Micro-Grid Lab of Hangzhou Dianzi University and Some Related Developments

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Outlines

1. HDU’s Micro-Grid Lab
2. PV modeling and monitoring model from bulk power grid
3. Feasibility study of PV and micro pumping storage for city and metropolis

Present 2 Micro-Grid Lab., Hangzhou Dianzhi University

1

- **Sino-Japanese Cooperation Micro-Grid Lab and demonstration project**
- Supported by NEDO Japan and Chinese Government in 2007
- 50% PV generation, 50% by Diesel Generation
- 120 kW PV installation, 120 kW Diesel
- Standby Super Capacitor (EDLC, Electric Double Layer Capacitor), Battery (lead-acid), Power Quality Controller (PQC), Instantaneous voltage dips compensator
- With Disturbance device for disturbance producer, and Simulation Load
- **Micro-Grid with Island Operation as well as tied with LV bulk power grid**
- **Start from 2007 and commissioned in end of 2008**
- **The 1st one of 50% PV** High penetration renewable resource in the World
- **The 1st one lab and demonstration project in China as a real operation Micro-Grid**
- **Cost near 27,000,000 RMB, or 27 Million RMB, or 3 Million US$**
- **2 teaching Building's roof of PV panels**
- **Very good operation and control for island/tied operation with EMS**

2

- China own technology Micro-Grid Lab and demonstration project
- 20kW PV, 10kW fuel cells, 10kW Wind power, Battery (lead-acid)
- 2,000,000 RMB, 2 Million RMB

For coming years

Present 2 Micro grids

- Sina-Japen 50% PV MG Lab
- Chinese Tech MG Lab

Campus Micro-grid

（adding more than 200 Million RMB）

Under Smart-city program and Campus Micro-grid demonstration project

- Campus Micro-grid Demonstration
- Customer Side Management System
- hybrid electric vehicle demonstration system

Some Pilot Studies

1
- Advanced Steady Grid-connected Micro-grid Demonstration Project of International Cooperation (China/Japan)
- Nedo Japan, NDRC(National Development and Reform Committee) China, 500 million Japanese yen, lead by Prof Shirong Liu, Jianmin Zhang

2
- Composite energy storage system Study for Micro-grid based on Battery and Super Capacitor
- State NSF, 0.2 Million RMB, lead by Prof. Xiaogao Xie, Jianmin Zhang

3
- Key Technical and Empirical Demonstration Grid Connected PV micro-grid
- Zhejiang Provincial Primary Industrial Program, 3.11 Million RMB , lead by Prof. Xie and Liu, Zhang

4
- PV generation system, PV station control and monitoring system
- Jianshan Ltd, Effison Energy Ltd. 2 Million RMB, lead by Prof.Shirong Liu

5
- Grid Connected PV station monitoring model and system,
- Zhejiang Electric Power Corporation, 0.6 Million RMB, Lead by Prof. Jianmin Zhang

6
- Impact of DG on the planning of Distribution Grid, and the guidance
- Zhejiang Electric Power Corporation, 0.5 Million RMB, Lead by Prof. Jianmin Zhang

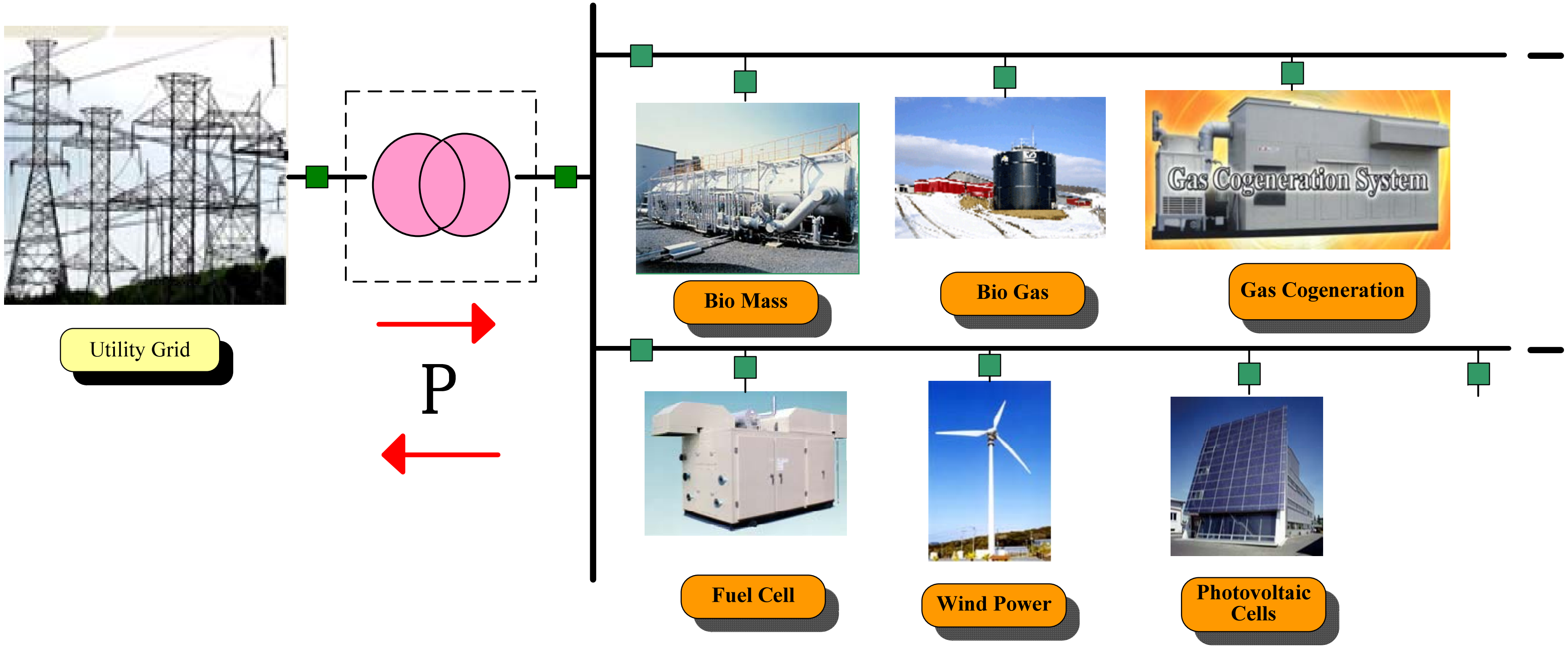
7
- **Feasibility Study of High-rise Building in City with PV and Micro-hydro Pumping Storage： Might be a Big Solution for Future City Smart & Micro Grid**
- Hangzhou Dianzi University, Lead by Prof. Jianmin Zhang

Distribution Generation and Micro-grid

Natural Energy

Renewable Energy

New Energy



Reduction of CO_2 Emissions

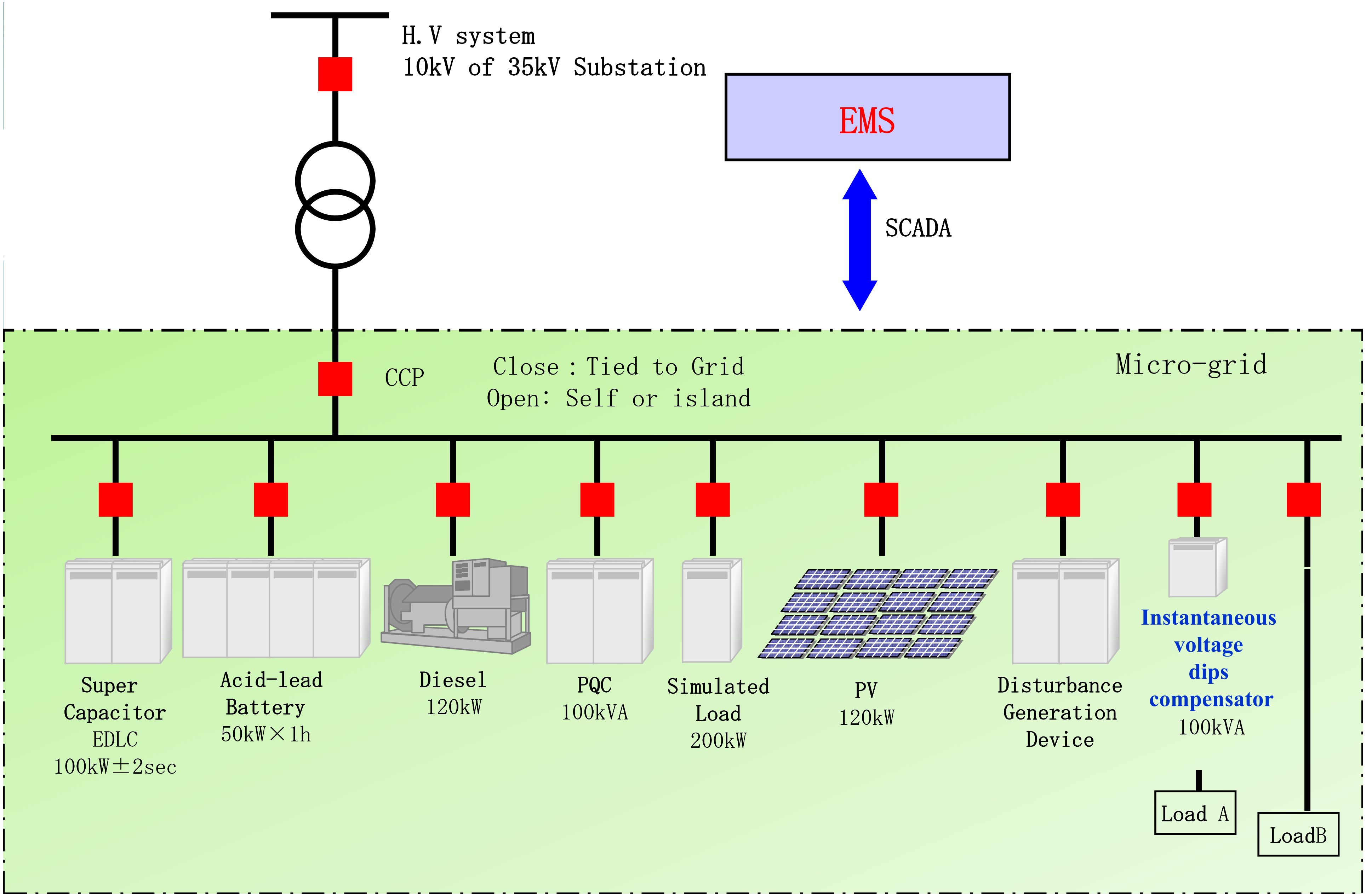
Energy Conservations / Energy Cost Saving

Advanced Steady Grid-connected Micro-grid Demonstration Project of International Cooperation (China/Japan)

Executive China: Hangzhou Dianzi University
Executive Japan: Shimizu construction technical research institute 清水建设

Total Gen.Capacity 240kW
PV: 120kW
Diesel : 120kW
Natural Sources up to 50%。

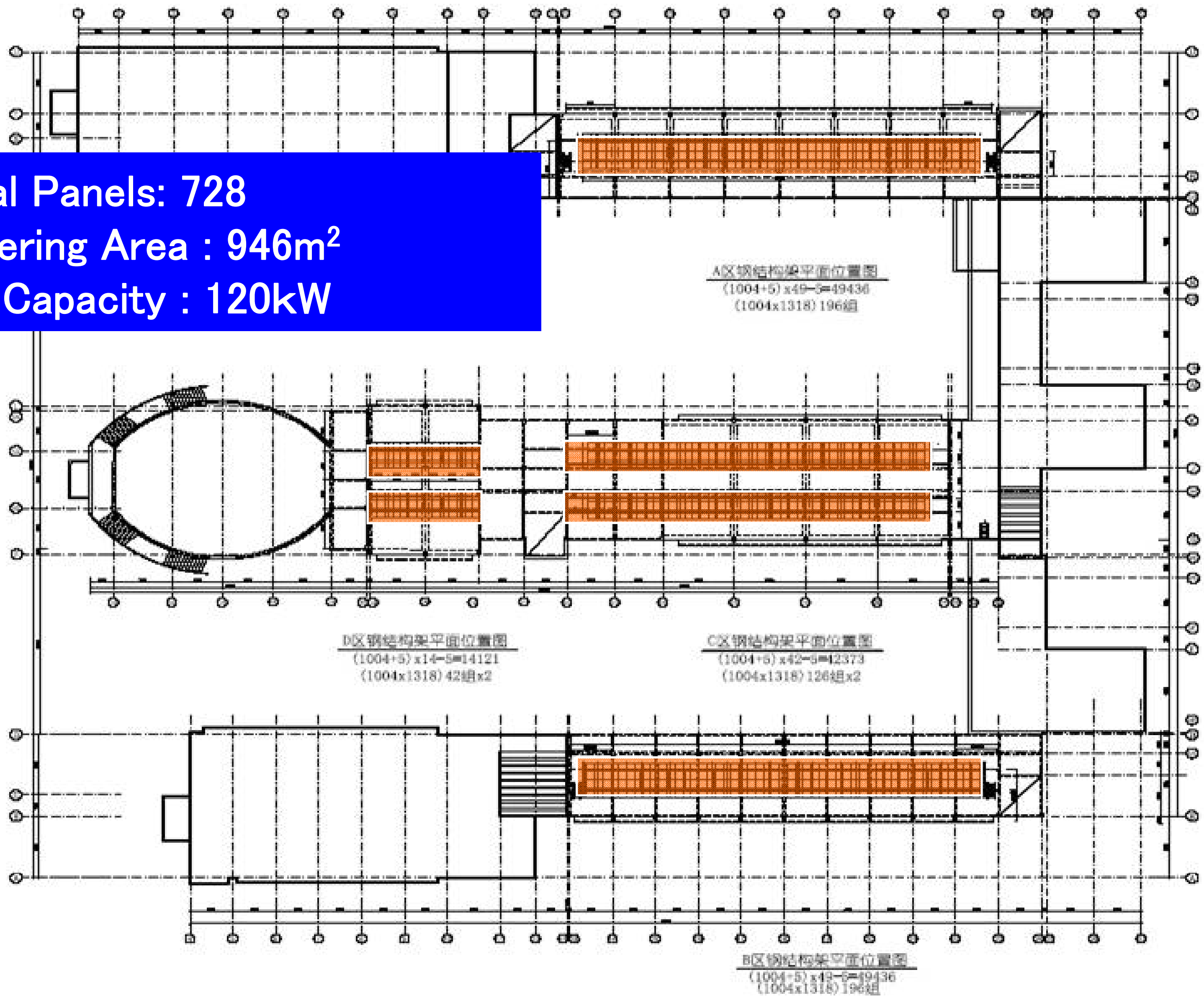
Sino-Japan Joint Micro-grid in HDU



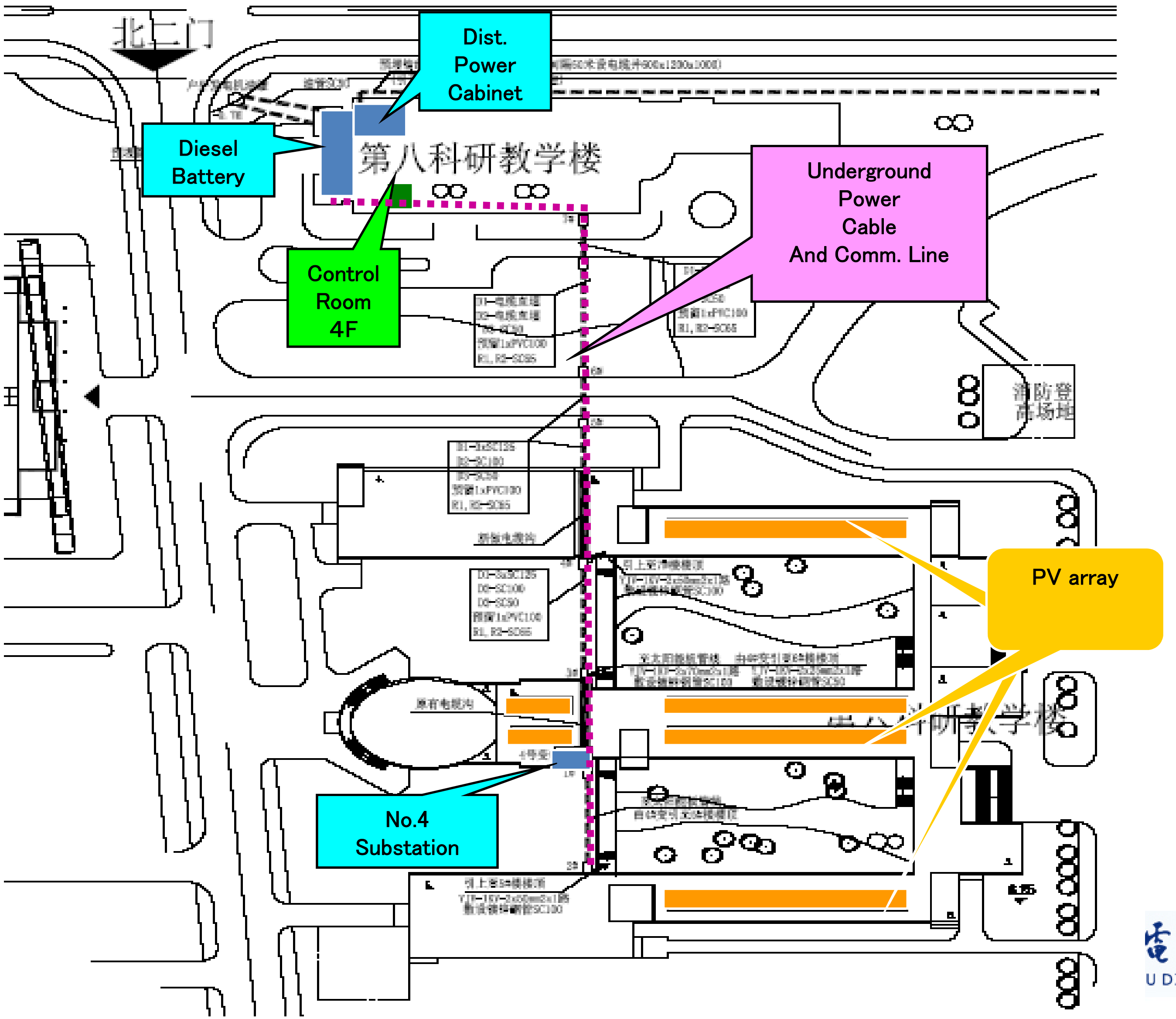
Sino-Japan Joint Micro-grid in HDU

PV panels (120 kW) configuration

Total Panels: 728
Covering Area : 946m^2
Full Capacity : 120kW



Sino-Japan Joint Micro-grid in HDU



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PV on roof




Diesel Generator、Acid-lead Battery

Diesel Set

Battery System

EDLC Super Capacitor system, PQC、Instantaneous voltage dips compensator

EDLC、PQC

Instantaneous voltage dips compensator

逆变器、并网连接、综合控制室

第4变电所

控制室

Project Milestone Records:

- ➢ Dec.,1,2007, start day of the project
- ➢ Aug., 2008, Installation and test completed, start trial operation
- ➢ Oct.,28,2008, Commission ceremony, start operation

Targets for Empirical Demonstration Study

High penetration of PV and other renewable and new energy generation, especially for city and metropolis

Great impacts on connected grid

Build a steady micro-grid under high penetration in nature and spontaneous change renewable generation sources

Technical empirical demonstration studies

- Grid-tied State: Steady power supply with less impact and friend co-operation with connected bulk power grid
- Independent and island State: Support high quality and steady operation in frequency and voltage

Detailed Studies

- Test and verification of power generation of Micro-grid
- Test and verification of control of supply and demand
- Test and verification of follow performance of instant, short periods (in seconds) power changes (impact on voltage and frequency)
- Test and verification of maximum penetration of PV like nature change renewable generation sources
- Simulation and analysis of grid-tied and island operation of micro-grid with high penetration

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■Electricity quality standards of independent or island micro-grid operation

	Standards or Specification of electricity quality
Standard Voltage	380V：380V±7%
frequency deviation	±0.1～0.3Hz（average）
Voltage flicker	△V10≦0.32V（average）
higher-order harmonics	3～5%（synthesize)

Special features of HDU micro-grid demonstration study

- **Micro-grid where PV up to 50%**
  - PV: 120kW Diesel: 120kW
- **Test and verification of steady operation in grid-tied and island**
  - Steady operation by EMS
  - Load change follow by battery and super capacity
  - Power quality by VQC and Instantaneous voltage dips compensator
- **Comprehensive and heavy test by Disturbance generation device to test power qualities**
  - Manual disturbance tests（voltage change, frequency change, flicker, higher-order harmonics, etc）
  - Test for different measure to maintain of power qualities

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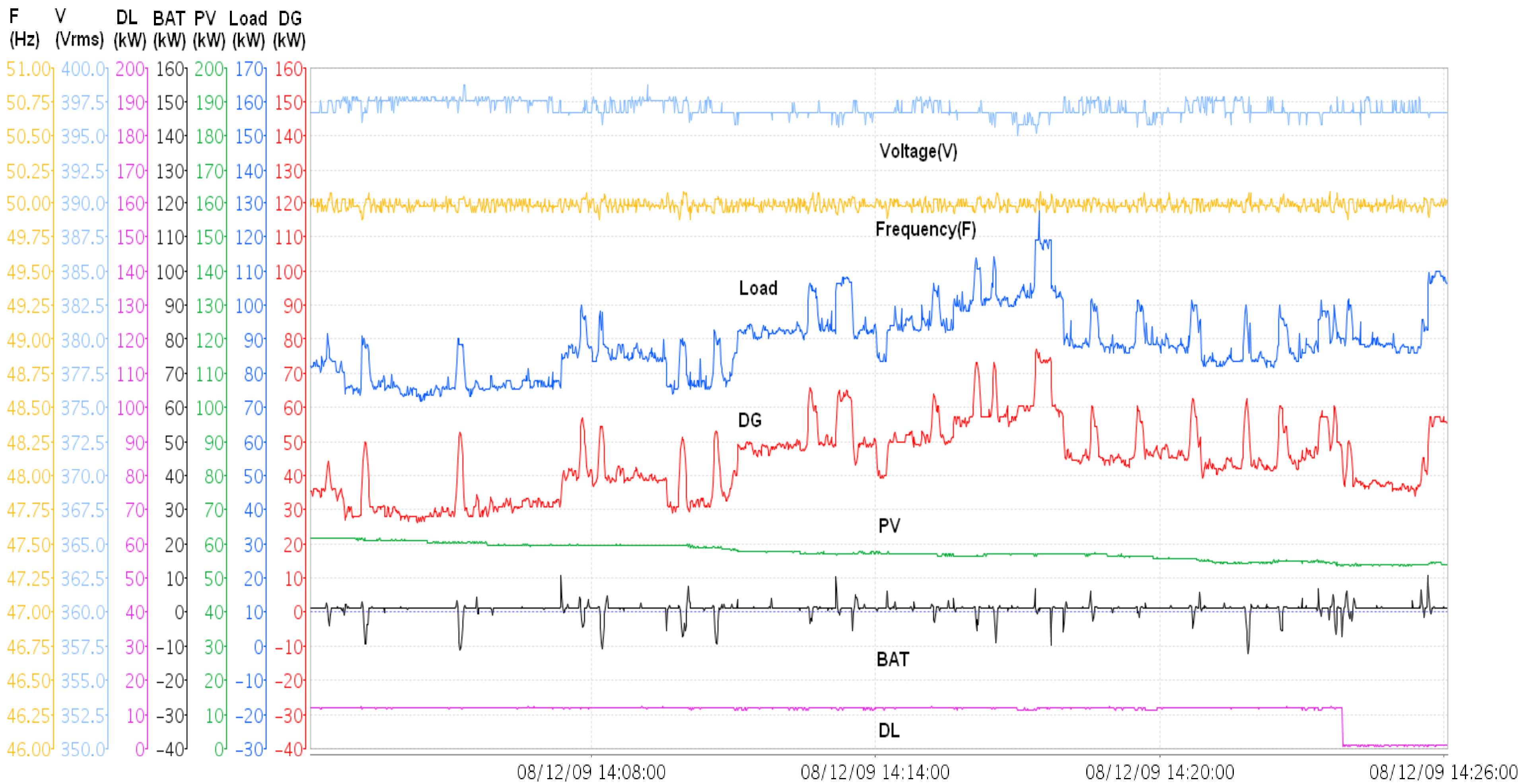
Island Mode Test



On island operation, the active power balance is achieved from un-balance or disturbance by co-operation by super capacitor (instant-quickest), battery (instant-quick), diesel (trend) to follow the change of PV output and change of load, to keep frequency in constant and steady, and using PQC and and Instantaneous voltage dips compensator to keep voltage in constant and steady

Other development from Sino-Japan Micro-grid Lab

- Planning, design, analysis and system implementation of PV boned Micro-grid
- Modeling and simulation of PV boned Micro-grid
- Steady control of island operation of PV boned micro-grid（by energy optimization, management and control）
- economic operation of PV boned Micro-grid in grid-tied as well as islanded

Outlines

1. HDU's Micro-Grid Lab
2. PV modeling and monitoring model from bulk power grid
3. Feasibility study of PV and micro pumping storage for city and metropolis

Photovoltaic plants are more and more widespread in the world, which should be monitored by their connected bulk power grid company.

By using PV module manufacture non-confidential datasheet, a practical PV plant model based on so called "2C PV Module Model" for the power grid company's metering system is provided.

A comprehensive parameter K is introduced into the model, which can be calibrated by trial or optimization method by using historical operation data, with no need of collection of topographic connection data as well as the detailed efficient coefficient parameters of energy transmission and converting of the plant, therefore greatly decreasing the modeling expenditure. Two useful models, in names of, minimum power calculation model, and maximum possible power prediction model with MPPT algorithm, have been explored for the power generation prediction, metering error or plant improper operation means prevention. The parameter sensitivity of model is also discussed for parameter assessment. Such model is validated by two operated PV plants.

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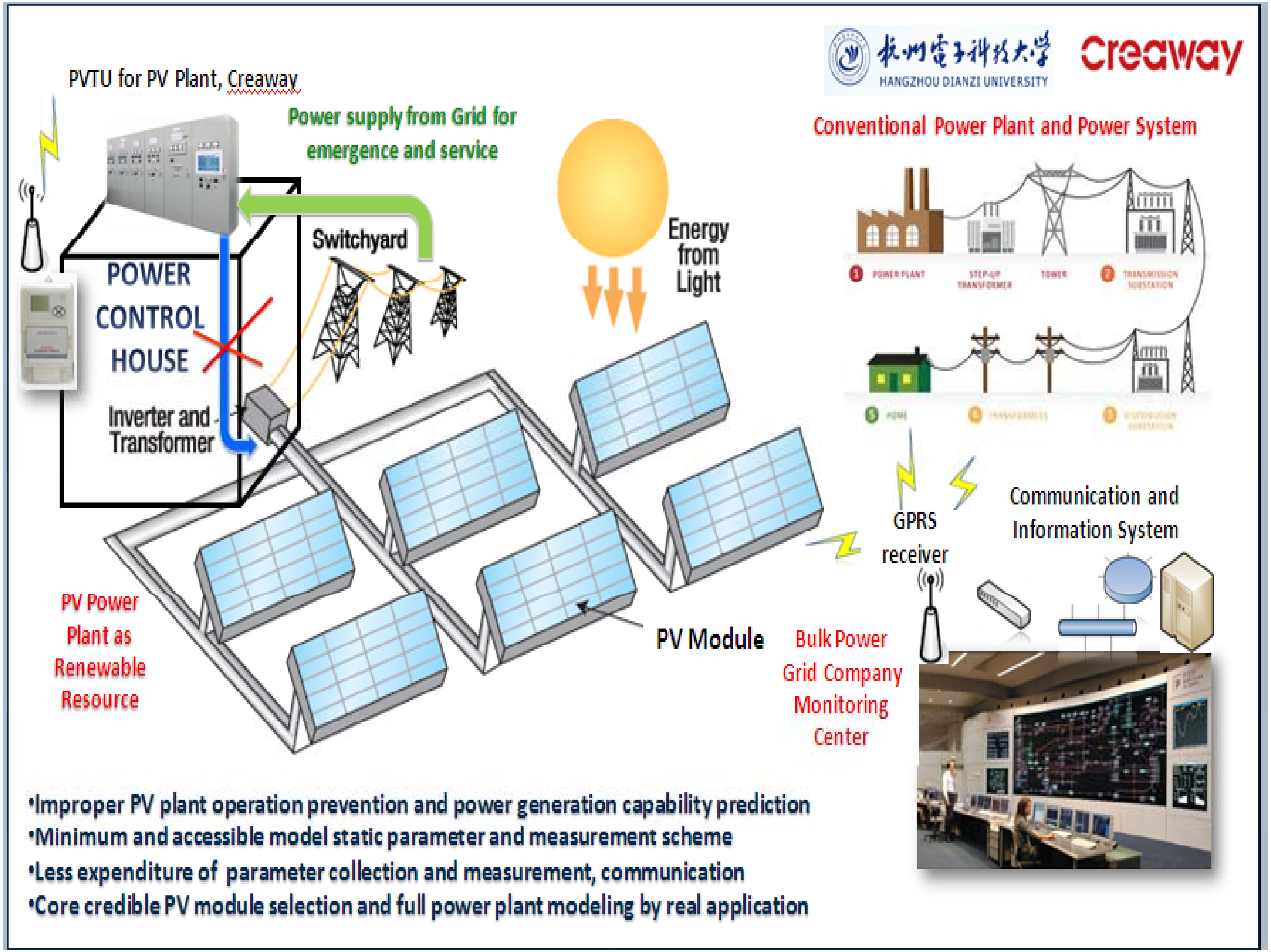

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Creaway
PVTU for PV Plant, Creaway
Power supply from Grid for emergence and service
Switchyard
Energy from Light
Conventional Power Plant and Power System
POWER CONTROL HOUSE
Inverter and Transformer
PV Power Plant as Renewable Resource
PV Module
GPRS receiver
Communication and Information System
Bulk Power Grid Company Monitoring Center
•Improper PV plant operation prevention and power generation capability prediction
•Minimum and accessible model static parameter and measurement scheme
•Less expenditure of parameter collection and measurement, communication
•Core credible PV module selection and full power plant modeling by real application

Why a PV plant should be monitored by grid company?

(1) Account Settlement for all PV plants.
(2) Power balance, control and dispatch only for medium and large size

What are main concerns of bulk power grid company?

(1) **Necessary:** the electricity of PV plant sending to power grid shares high price, but it should be generated fully and credibly from Solar energy, otherwise there must be an abnormal even cheating event happened, therefore the energy transfer process should be monitored and recorded, so modeling of PV plant and suitable monitoring system should be implemented;
(2) **Practical Technology and Economical Considerations:** authentic model with less measurements, less and accessible static parameter scheme, under a certain accuracy. So the modeling should be carefully studied.
(3) **Capability of power generation of PV plant:** possible maximum power generation curve, and minimum power generation curve of PV plant under a certain solar irradiance condition.

PV Module Model using Manufacture Data Sheet

2C PV module model by Borowy & Salameh in 1996.

$$I = I_{SC}\left(1 - C_1\left(\exp\left(\frac{V - \Delta V}{C_2 V_{OC}}\right) - 1\right)\right) + \Delta I \quad (1)$$

$$\Delta V = -\beta \cdot \Delta T - R_s \cdot \Delta I \quad (2)$$

$$\Delta I = \alpha \frac{R}{R_{ref}} \Delta T + \left(\frac{R}{R_{ref}} - 1\right) I_{SC} \quad (3)$$

$$\Delta T = T_C - T_{ref} \quad (4)$$

$$C_1 = \left(1 - \frac{I_m}{I_{SC}}\right)\exp\left(-\frac{V_m}{C_2 V_{OC}}\right), \quad C_2 = \left(\frac{V_m}{V_{OC}} - 1\right) / \ln\left(1 - \frac{I_m}{I_{SC}}\right) \quad (5)$$

$$T_C = T - t_c R \cos\theta \quad (6)$$

Where I_{sc}, V_{oc}, V_m, I_m are data of Standard Test Condition (STC); α, β are current temperature correlation in Amps/℃ and voltage temperature correlation in V/ ℃; R_s is cell internal series resistance (Ω); R, T, θ are measured radiation, temperature and angle of radiation; t_c is the temperature coefficient of PV cell; V, I are current and voltage of PV module.

$t_c R \cos\theta$ is relatively smaller, so we can take:

$$T_C = T \quad (7)$$

Full PV Plant Model

Assuming PV array consists of m string modules in parallel, each string consists of n modules in series which are with same type of cell, and the total output current is I_{tl} , terminal voltage is U_{tl} , total power is P_{tl} , so:

$$I_{tl} = mI, \quad U_{tl} = nV, \quad P = IV \tag{8}$$

$$P_{tl} = \eta_R I_{tl} U_{tl} = \eta_R mnIV = \eta_R mnP \tag{9}$$

η_R is overall transmission efficiency of the PV array. If a system with single inverter, its efficiency is η_I, transformer efficiency is η_T, then grid output power:

$$P_g = \eta_I \eta_T P_{tl} = \eta_I \eta_T \eta_R mnIV \tag{10}$$

If a system uses different connection of PV array with multi-inverters, we can have a similar Pg formula accordingly. Inverter manufacturers usually provide η_I, η_T in non-linear curve, but η_R requires on-site measurement and it is not easy to obtain. Therefore, to reduce the amount of work and be easy for calculation, rated efficiency, i.e $\bar{\eta}_T$ $\bar{\eta}_I$ are used.

Assuming there are L number of PV inverter groups in parallel to supply the power to the grid, then we have (10) by introducing a comprehensive efficiency factor K (where transmission efficiency of the PV array is considered into K):

$$Pg = \sum_{i=1}^{L} \eta_{Ti}\eta_{Ri}\eta_{Ii} m_i n_i I_i V_i = K \sum_{i=1}^{L} \bar{\eta}_{Ti} \bar{\eta}_{Ii} m_i n_i I_i V_i \tag{11}$$

Minimum Power Calculation Model (MinPM)

By using measured data of PV array's voltage V (we use the terminal voltage measured to be divided by the n), solar irradiance R, ambient temperature T, and using equation (1)-(11), we can calculate $P_g(t)$ as in (10).

Normally PV plant operates using maximum power tracking (MPPT), but the equations (1)-(11) have not considered with the function of MPPT, so that P_g should be less than the measured real power sold to the grid, therefore we can call (1)-(11) as the ***minimum power calculation model (MinPM).***

Maximum Possible Power Prediction Model (MaxPM)

As MPPT is widely used, we can also using MPPT to predict the maximum possible power of the plant. The plant in its maximum power point:

$$dP_d / dU_d = 0 \tag{12}$$

From (8), (9) we have:

$$dU_d = ndV, \quad dP_d = \eta_R mndP \tag{13}$$

Putting into (12), we have

$$dP_d / dU_d = \eta_R mdP / dV = 0 \tag{14}$$

Which means that when PV modules are at maximum power point, the total PV array will be at the maximum power point; so we have:

$$P_{ti,max} = \eta_R mnP_{max} \tag{15}$$

For the entire plant:

$$P_{gmax} = \sum_{i=1}^{I} \eta_{Ti}\eta_{Ri}\eta_{Ii}m_i n_i P_{max,i} = K\sum_{i=1}^{I} \overline{\eta}_{Ti}\overline{\eta}_{Ii}m_i n_i P_{max,i} \tag{16}$$

According to the measured R,T, using equation (1)-(9), (11)-(14) to get the maximum power, and use (15)-(16) to calculate P_{gmax} (t). Such calculation is with a globe MPPT function and (7) is trending to have a greater power output, so that P_{gmax} should be great than the measured real power sold to the grid, so we can call Pgmax as the **maximum possible power prediction model (MaxPM)**

Monitoring the "Appropriateness" of PV Plant

If the measured power output is $P_m(t)$, it must meet :

$$P_{gmax}(t) \geq P_m(t) \geq P_g(t) \qquad (17)$$

Otherwise, check for measurement error or clarification should be done. Above (17) only consider the net power generation from PV array. If a plant has storage equipment or local load, then they should be measured separately, and reported to bulk power grid company.

Calibration of Comprehensive Efficiency Parameter K

The comprehensive efficiency parameter K has its ranges from 0.6 to 0.95. It can be got by trial method by K selection to meet (17), or optimization as following:

$$\begin{aligned} \min\ &: c_1\{MAE(P_{g\max}, P_m) + MAE(P_m, P_g)\} \\ &+ c_2\{RMSE(P_{g\max}, P_m) + RMSE(P_m, P_g)\} \\ sub\ to\ &: EE(P_{g\max}, P_m) > 0 \\ &EE(P_m, P_g) < 0 \end{aligned} \tag{18}$$

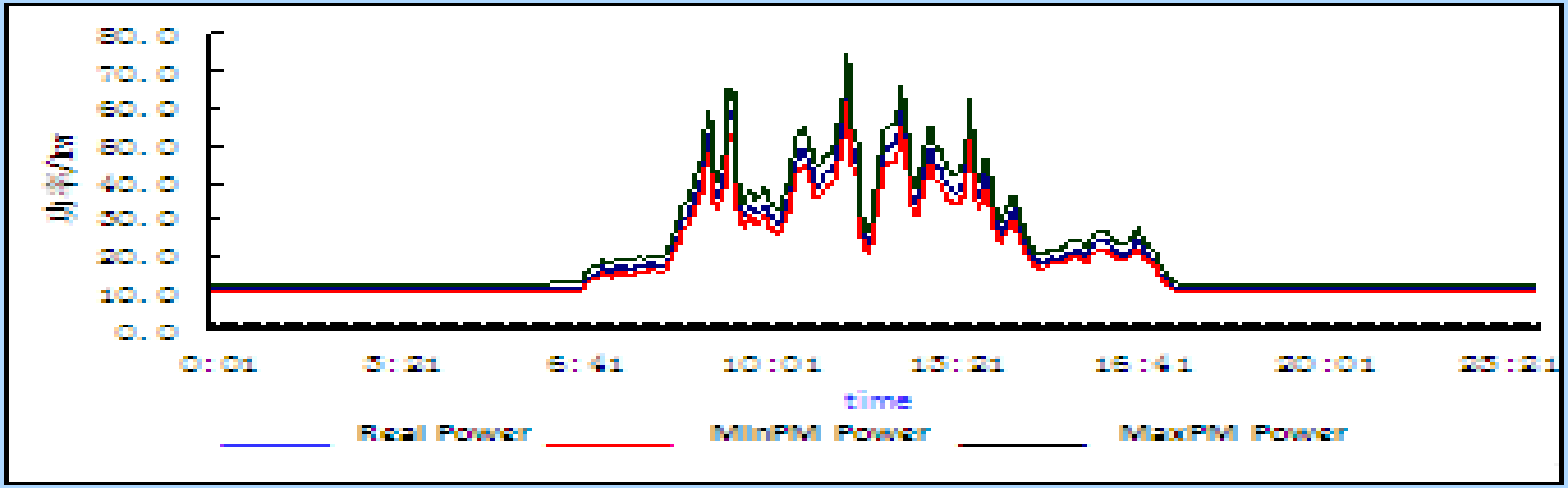
where MAE, RMSE, EE are mean absolute error, root mean square error, average error.

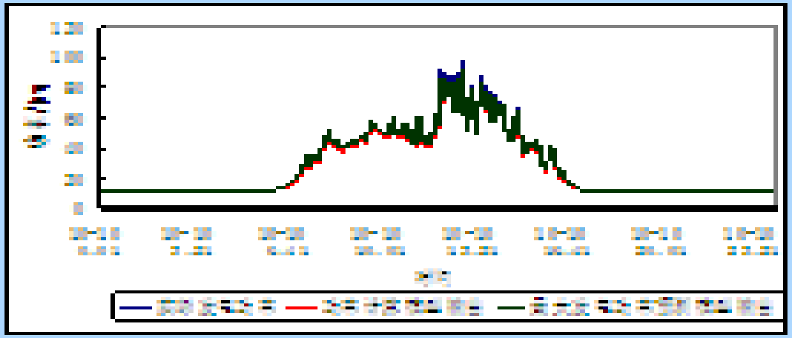
Accuracy Check of Minimized Static Parameters and Measurements

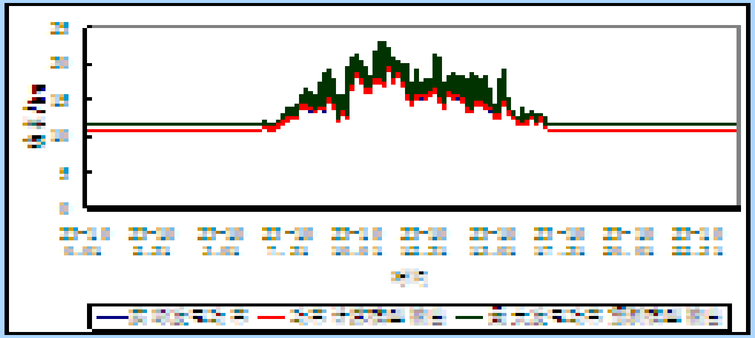
Sensitivity analysis is used to analyze the importance of already minimized model parameters, which helps the bulk power grid company to put forward an accuracy requirement of static parameters as well as the measurements, to the authority of PV plants.

Simulation and Application

Two demonstration micro-grids with PV, i.e., Hangzhou Dianzi University's and Institute of Electric Power Sci.& Tech., were under testing and good results were achieved. See curves as following. The software was made and embedded into Zhejiang Electrical Energy Metering Information System.







Conclusion

The additional monitoring items for renewable power plants should be carefully studied to achieve a clear targets, realistic scheme for static parameter access method, economic scheme for additional measurement and communication system design, scientific and suitable modeling, to achieve an effective and efficient information system solution. Above work has meet such requirement.

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Three primary storage technology

- Potential Energy 势能，如弹簧储能
- Chemical Energy 化学能 如电池
- Gravitational Energy 重力能，主要以水电能

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Storage for a secure Power Supply from Wind and Sun, an European study

. By Germany professors Reinhard Leithner et al， Storage for a secure Power Supply from Wind and Sun, http://www.poppware.de/Links_und_Downloads/Matthias_Popp-Storage_for_a_secure_Power_Supply_from_Wind_and_Sun.pdf

For only use of renewable energy, is it possible to develop a safety of power supply measures to balance and storage of consumer demand? Germany three professors, Braunschweig university of heat and fuel institute of technology Prof. Dr. Reinhard Leithner, Oldenburg university institute of physics Prof. Dr. Juergen Parisi and the university of BoHongLuEr energy system and energy economic research institute, Prof. Dr. Hermann-Josef Wagner common write a paper, "Speicherbedarf bei einer Stromversorgung MIT Erneuerbaren Energien" (use of renewable energy to meet the demand for storage), on the above issues to be the answer.

Ringwallspeicher-Hybridkraftwerk (Ringwall-storage-hybrid power plant)

Storage for a secure Power Supply from Wind and Sun, an European study

. By Germany professors Reinhard Leithner et al, Storage for a secure Power Supply from Wind and Sun, http://www.poppware.de/Links_und_Downloads/Matthias_Popp-Storage_for_a_secure_Power_Supply_from_Wind_and_Sun.pdf

For only use of renewable energy, is it possible to develop a safety of power supply measures to balance and storage of consumer demand? Germany three professors, Braunschweig university of heat and fu… …nhard Leithner, Oldenburg university institute of ph… energy system and ener… common write a paper, … Energien" (use of renewable energy to meet … ans…

power plant has a … kilometers (7.03 mil… meters (70…

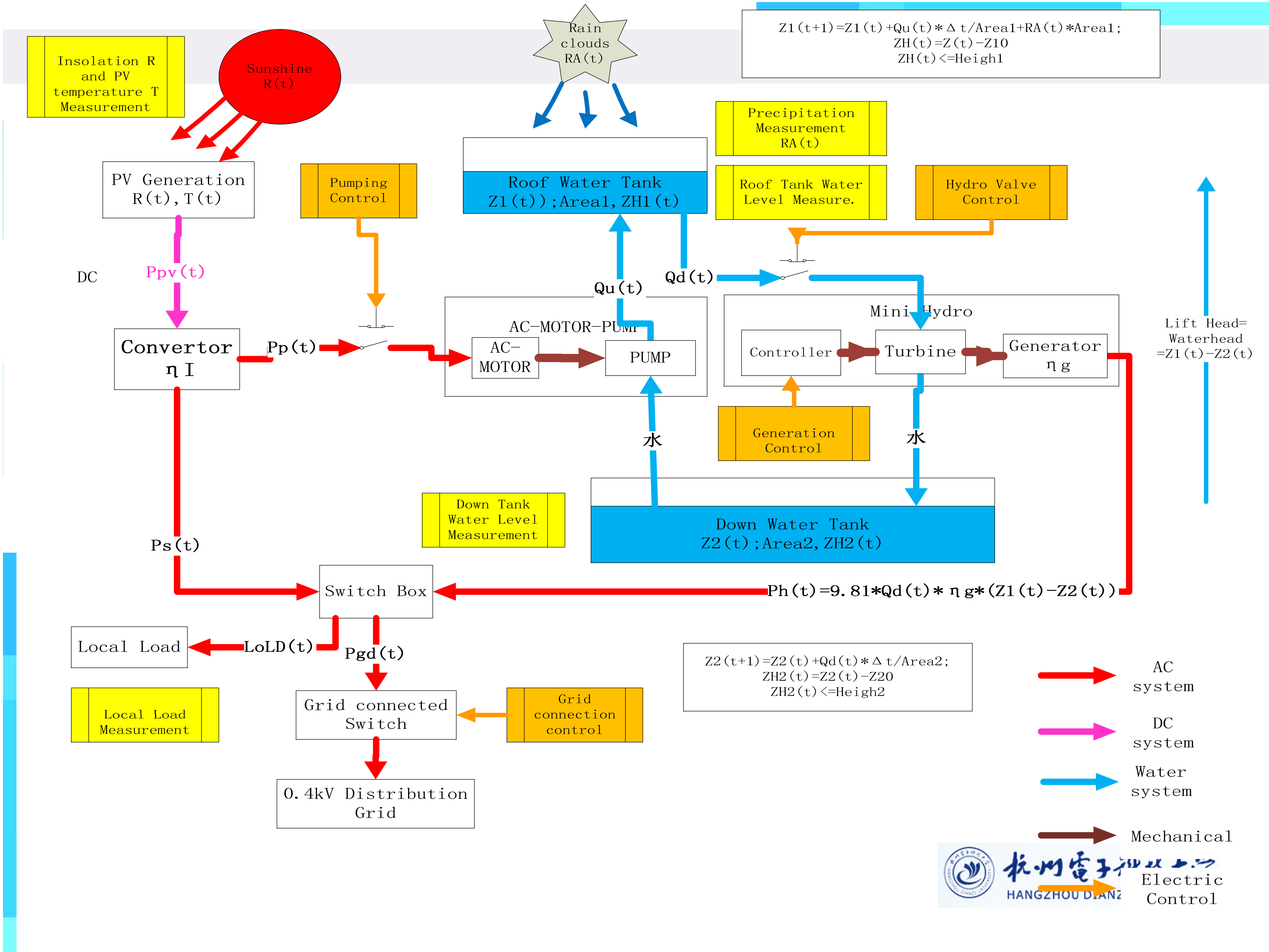
The biggest water in the pool is above 164 feet (50 meters) … feet), the averag… …es (656

Combined with about 2000 wind power plant (center height such as 160 meters (525 feet), rotor diameter 120 meters (394 feet)), the device can replace two nuclear power plant and safe for the power output to meet demand.

The above pools and the south side of the mountain is solar power plants

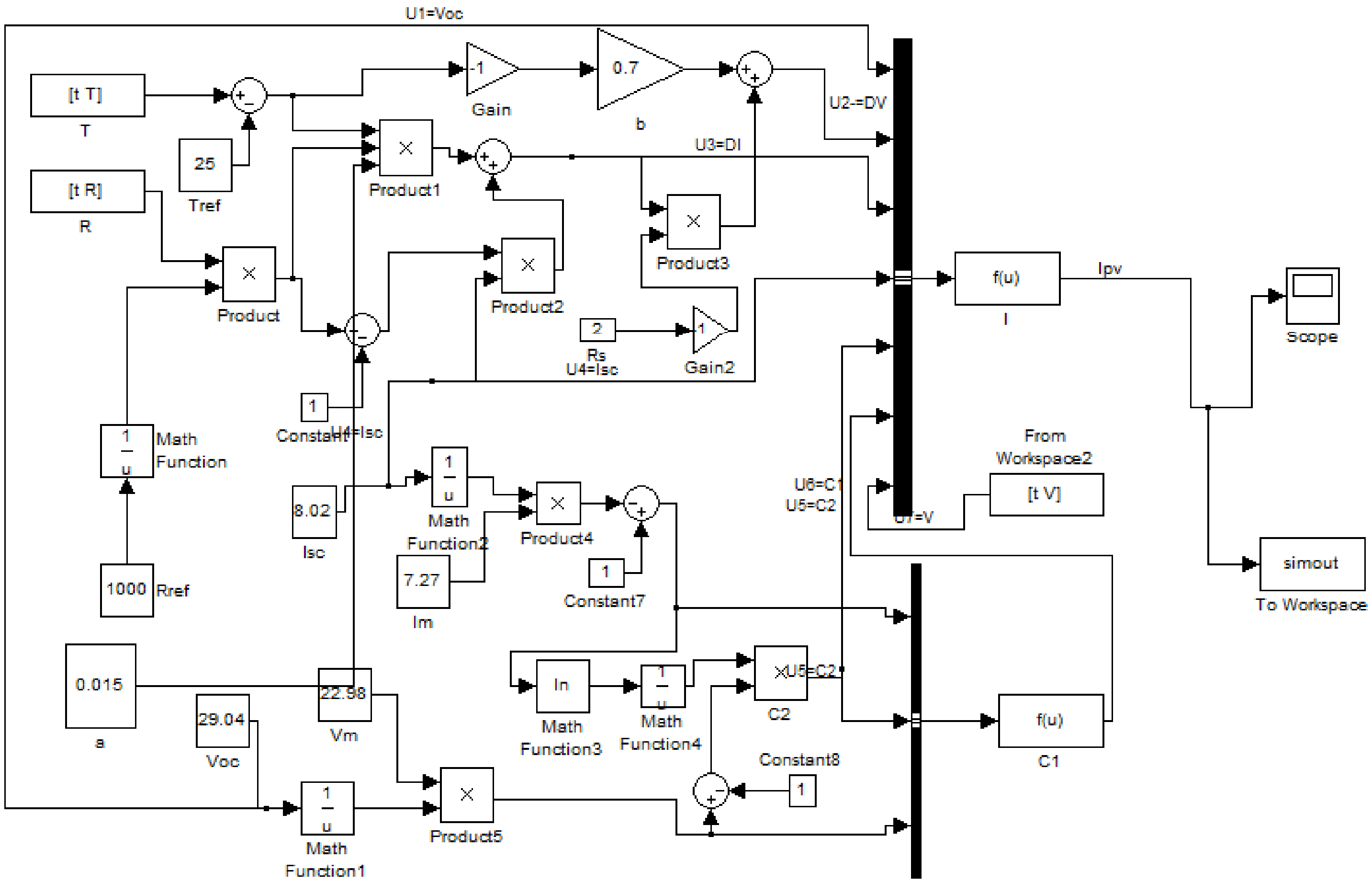
What is special in city and metropolis

1) High-rise Buildings are main in eye-seeing
   High-rise = high height of gravity potential
   Water is essential, so hydro power, so bumping storage
2) High density of Load, Load center,
   High difference of peak and off-peak, accessible and large quantity of peak/off-peak regulation devices are most in need and indeed
3) Roof PV and building PV for generation,
   Roof rainfall collection is encouraged by government
4) The water system as well as pumping system are already there for high-rise buildings as used for fire protection, drink water supply, swim pool, sanitation system, etc
   where water storage tank in roof, as well as underground.



Insolation R and PV temperature T Measurement
Sunshine R(t)
Rain clouds RA(t)
Z1(t+1)=Z1(t)+Qu(t)*Δt/Area1+RA(t)*Area1;
ZH(t)=Z(t)-Z10
ZH(t)<=Heigh1
Precipitation Measurement RA(t)
PV Generation R(t),T(t)
Pumping Control
Roof Water Tank Z1(t));Area1,ZH1(t)
Roof Tank Water Level Measure.
Hydro Valve Control
DC
Ppv(t)
Qu(t)
Qd(t)
Mini Hydro
Lift Head= Waterhead =Z1(t)-Z2(t)
Convertor ηI
Pp(t)
AC-MOTOR-PUMP
AC-MOTOR
PUMP
Controller
Turbine
Generator ηg
水
Generation Control
水
Down Tank Water Level Measurement
Down Water Tank Z2(t);Area2,ZH2(t)
Ps(t)
Switch Box
Ph(t)=9.81*Qd(t)*ηg*(Z1(t)-Z2(t))
Local Load
LoLD(t)
Pgd(t)
Z2(t+1)=Z2(t)+Qd(t)*Δt/Area2;
ZH2(t)=Z2(t)-Z20
ZH2(t)<=Heigh2
AC system
Local Load Measurement
Grid connected Switch
Grid connection control
DC system
Water system
0.4kV Distribution Grid
Mechanical
Electric Control

PV SIMULINK model with T and R in 1440 minutes



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PV SIMULINK model with MPPT

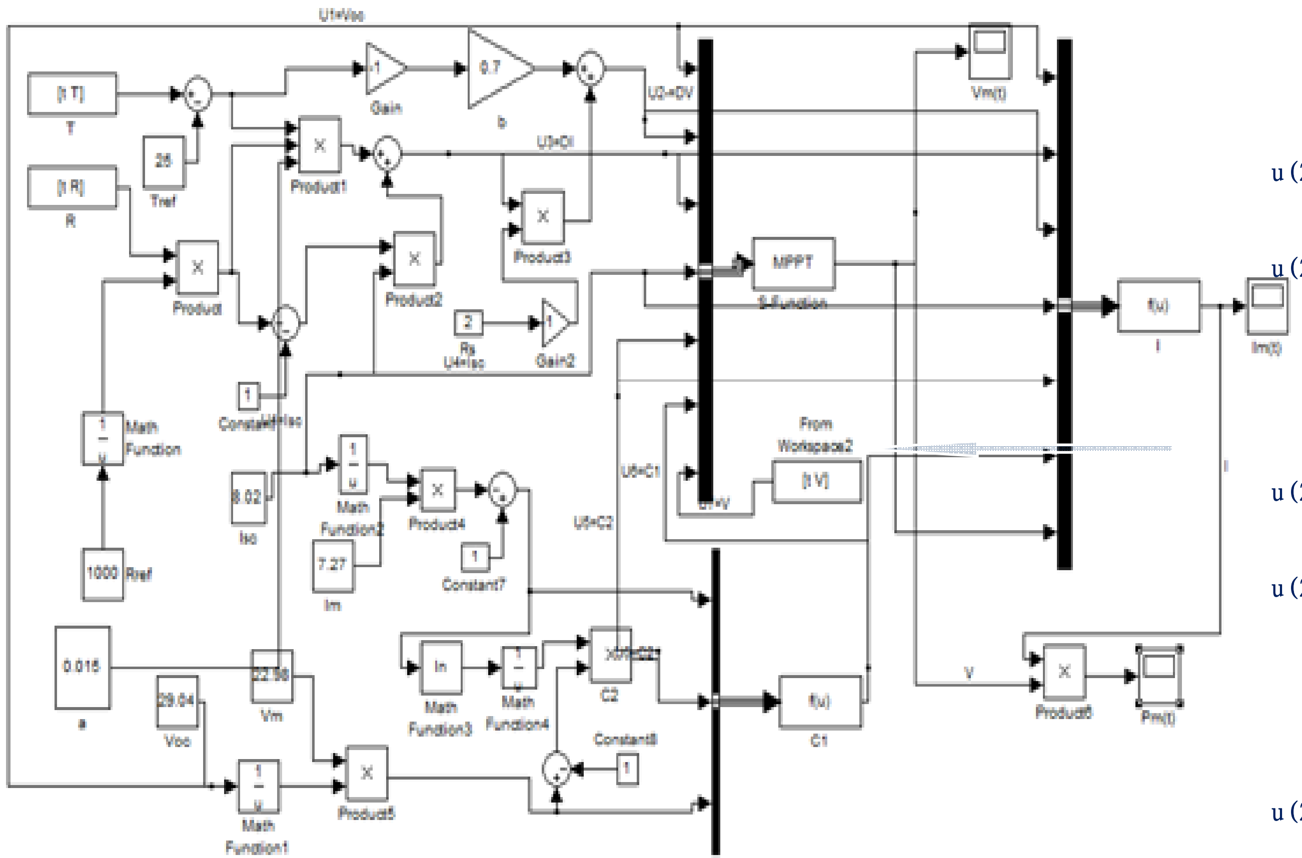

Figure 3.16 PV SIMULINK model with simple MPPT function

```
        sys=md10utputs(t,x,u,k1,k2,k)
    x(1)=u(7);
     x(3)=x(1)*(u(4)*(1-u(6)*(exp((x(1)-
u(2))/u(5)/u(1))-1))+u(3));
     x(2)=x(2)+k1;
     x(4)=x(2)*(u(4)*(1-u(6)*(exp((x(2)-
u(2))/u(5)/u(1))-1))+u(3));
     k2=(x(4)-x(3))/(x(2)-x(1));
     k=abs(k2);
   while k>k1
         if k2>0
           x(1)=x(1)+k1;
           x(3)=x(1)*(u(4)*(1-u(6)*(exp((x(1)-
u(2))/u(5)/u(1))-1))+u(3));
           x(2)=x(1)+k1;
           x(4)=x(2)*(u(4)*(1-u(6)*(exp((x(2)-
u(2))/u(5)/u(1))-1))+u(3));
           k2=(x(4)-x(3))/(x(2)-x(1));

           k=abs(k2);
         else
           x(1)=x(1)-k1;
           x(3)=x(1)*(u(4)*(1-u(6)*(exp((x(1)-
u(2))/u(5)/u(1))-1))+u(3));
           x(2)=x(1)-k1;
           x(4)=x(2)*(u(4)*(1-u(6)*(exp((x(2)-
u(2))/u(5)/u(1))-1))+u(3));
           k2=(x(4)-x(3))/(x(2)-x(1));

           k=abs(k2);
         end
   end
```

Each PV curve has a different maximum power point ( ), this is the best working point of the solar cell. In order to make full use of the solar cell, we use the maximum power point tracking (MPPT - Maximum Power Point the Tracking).

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Pumped-storage system

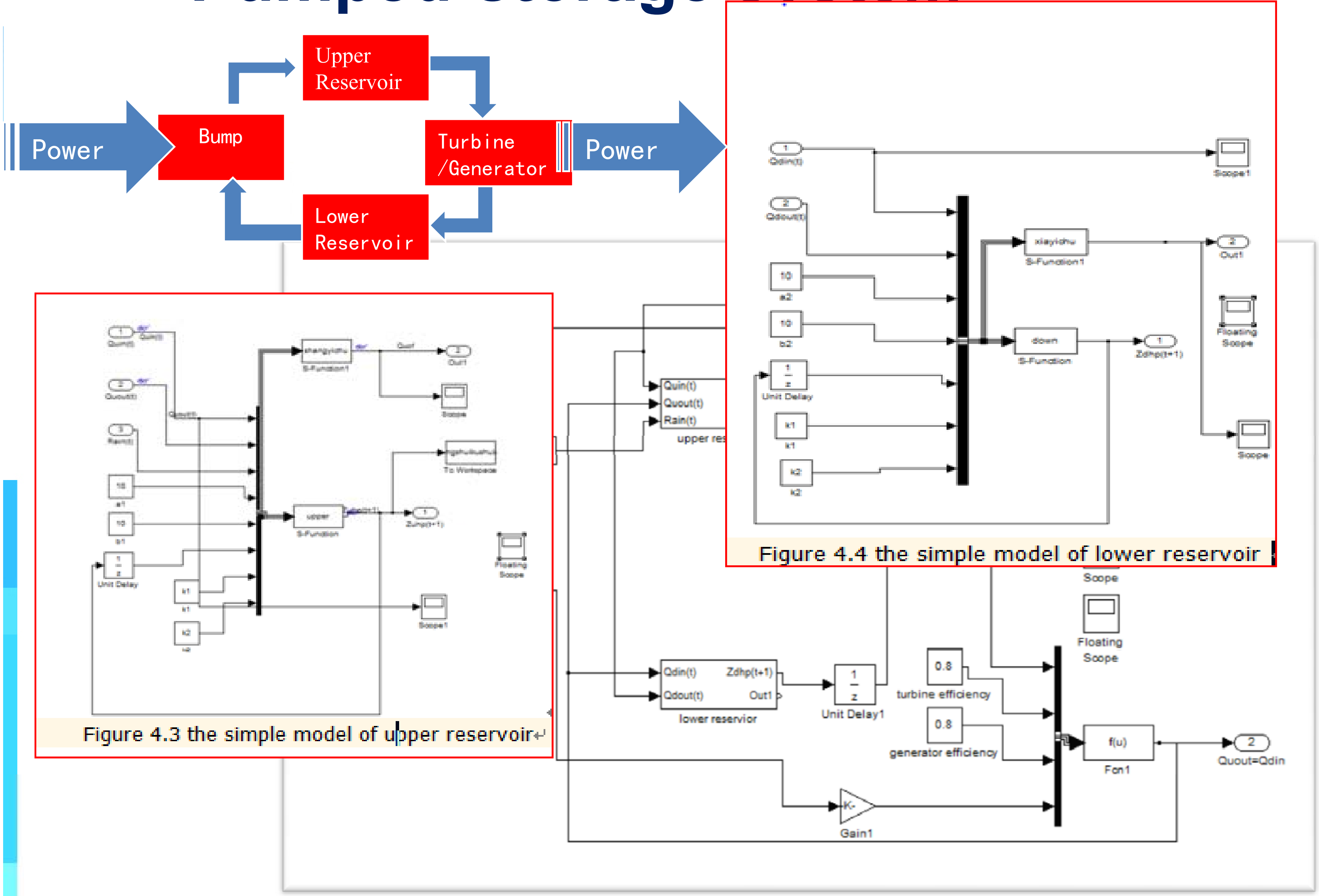
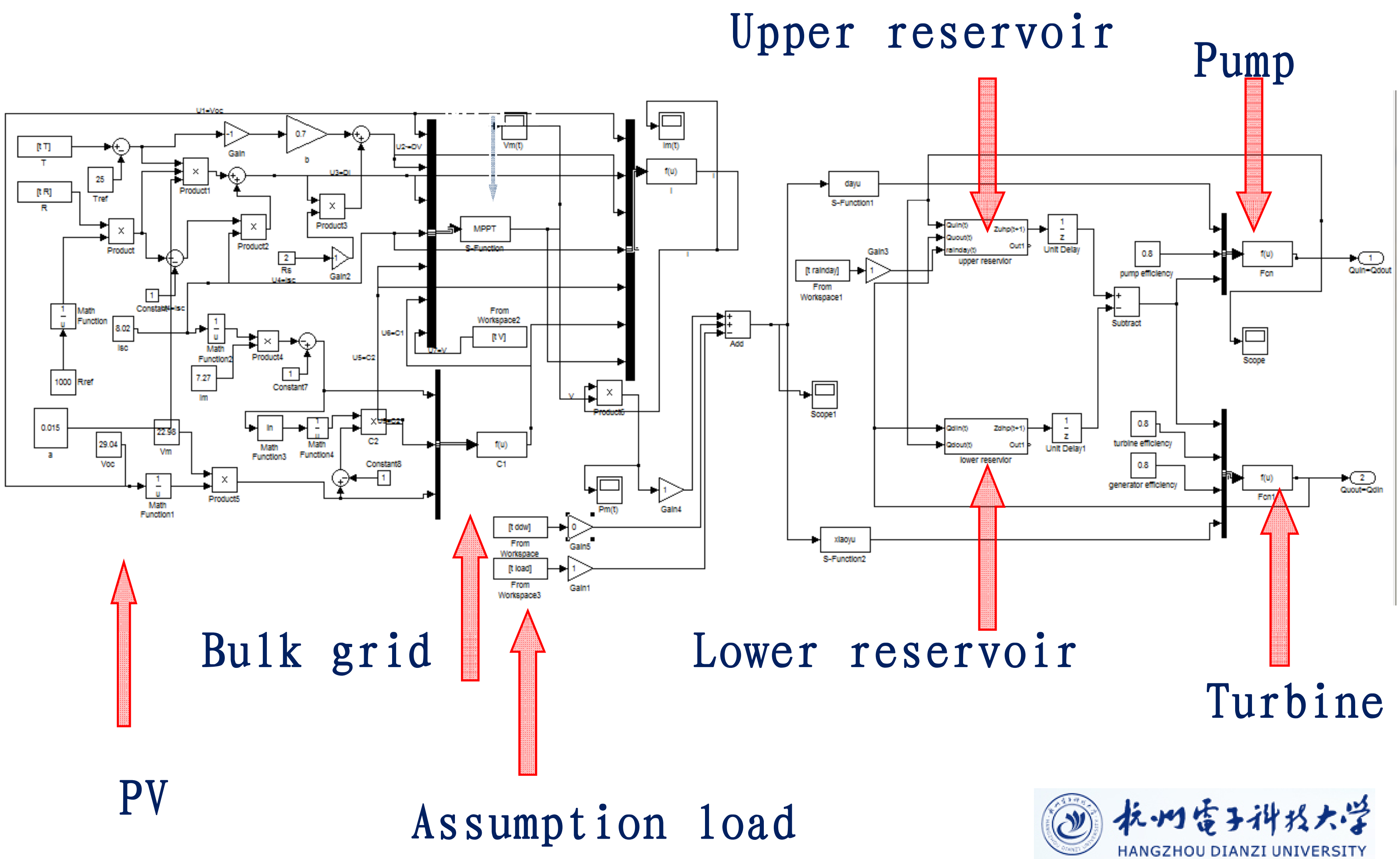


Figure 4.3 the simple model of upper reservoir

Figure 4.4 the simple model of lower reservoir

Joint system SIMULINK model



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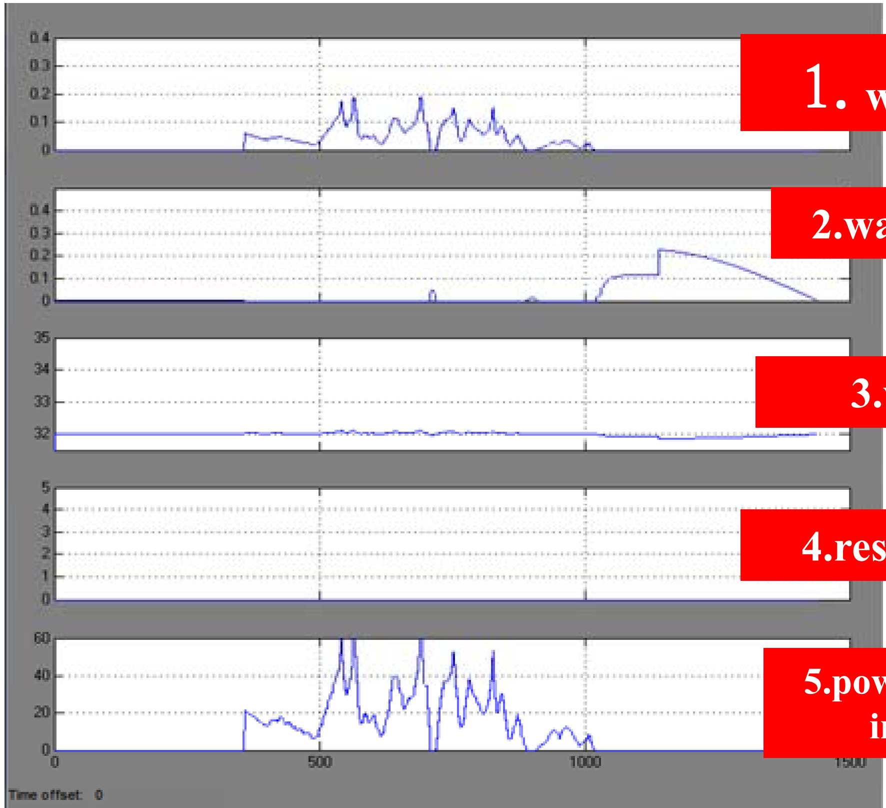
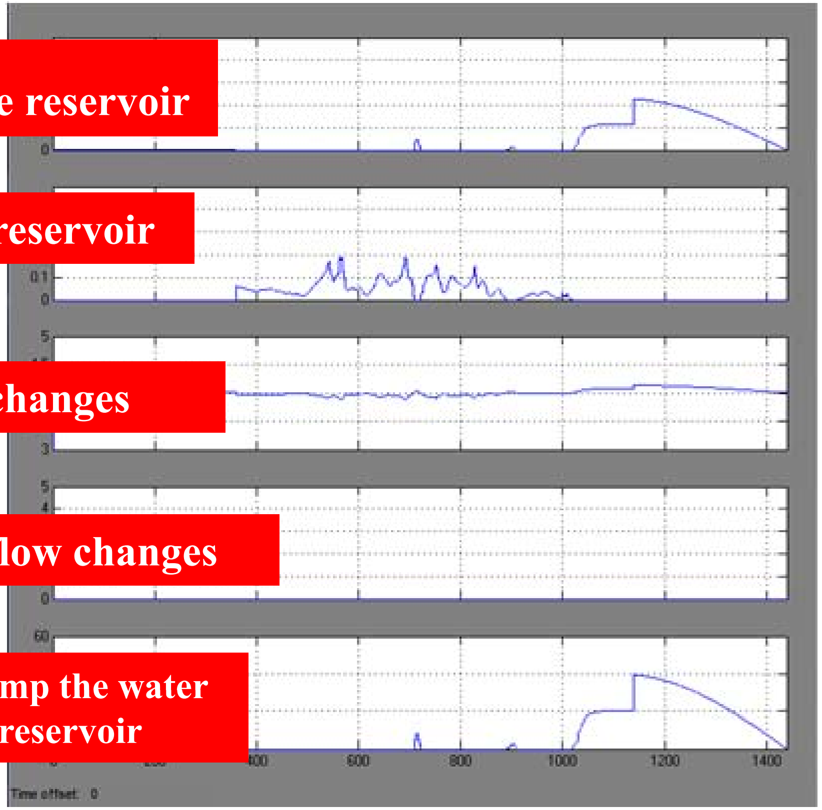
Case 1. Fine weather , PV (100%)

Upper reservoir

Lower reservoir





1. water into the reservoir

2.water out the reservoir

3.water level changes

4.reservoir overflow changes

5.power used to pump the water into the upper reservoir

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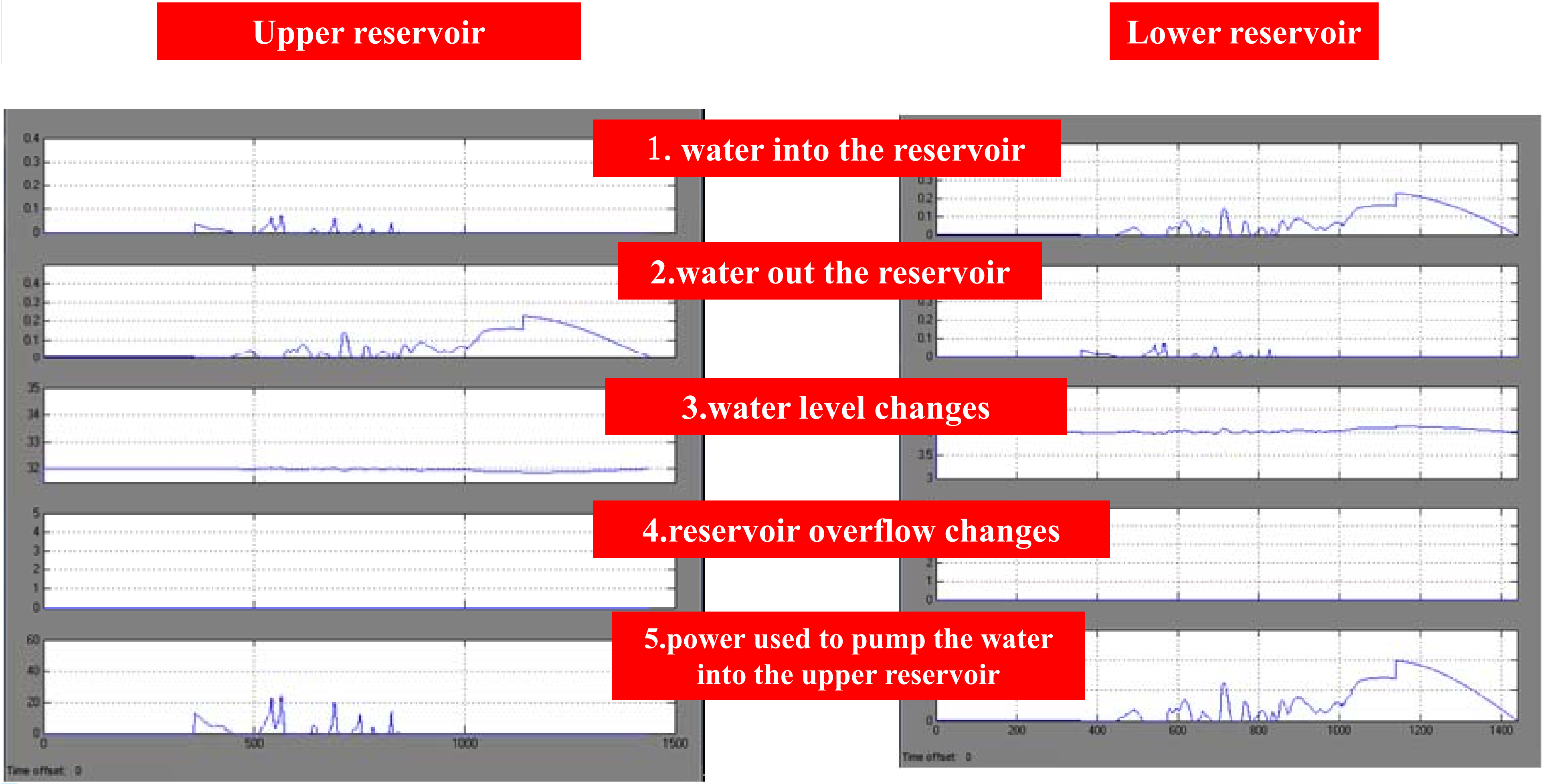
Case 2. cloudy weather, PV (60%)



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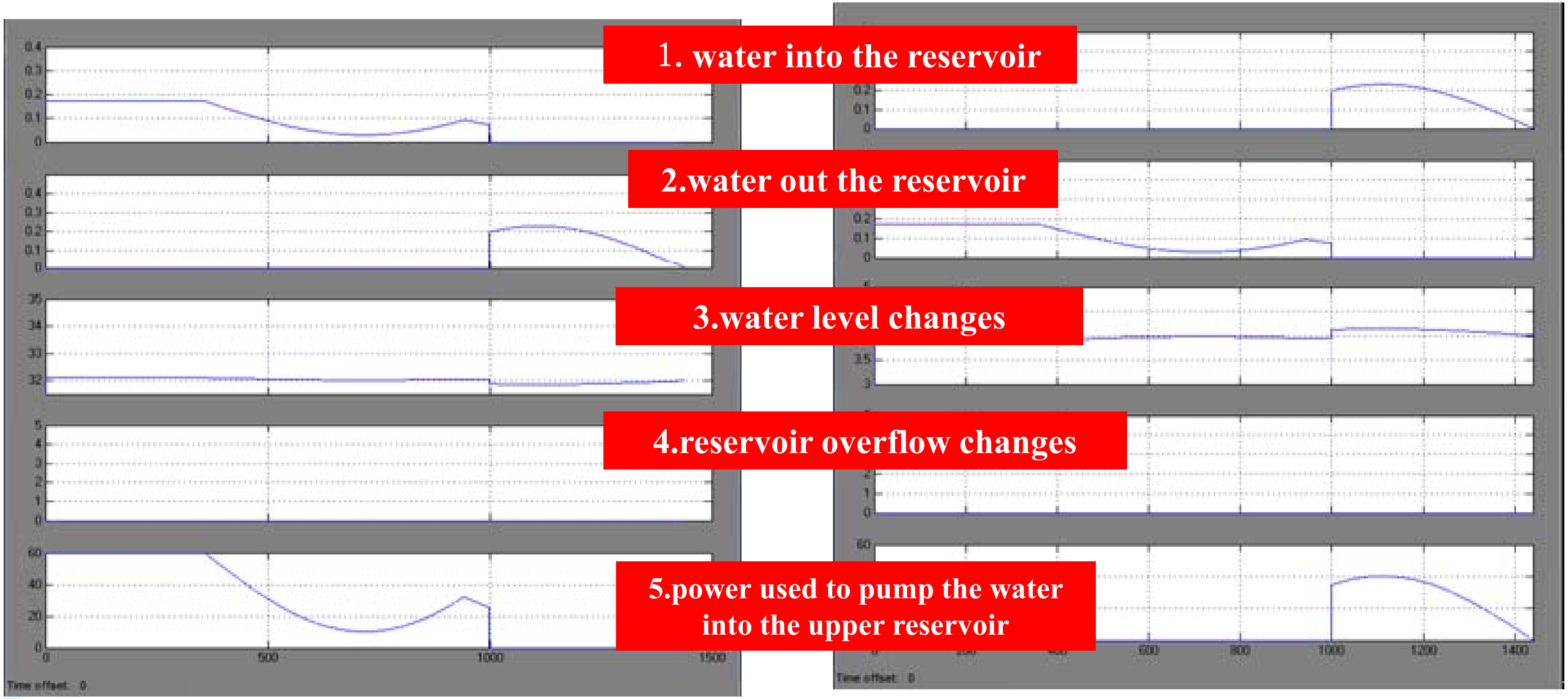
3.Rainy weather , PV(0%)

Upper reservoir

Lower reservoir



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More further work should be done

- 1 The efficiency of small pump in the real work is not high, but some researches present that efficiency of pump can be improved by using power electronics technology and cascade pumping.
- 2 Larger capacity of roof tank can regulate more PV power and more peak\off-peak regulation capability for the bulk grid. But the increasing of roof burden may also increase supporting architecture of the whole building. A deeper research about this problem is needed.

Thank you for your attention!

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